Asphalt Research Consortium

Characteristics of the Loading Pulse for the Flow Number Performance Test

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Introduction

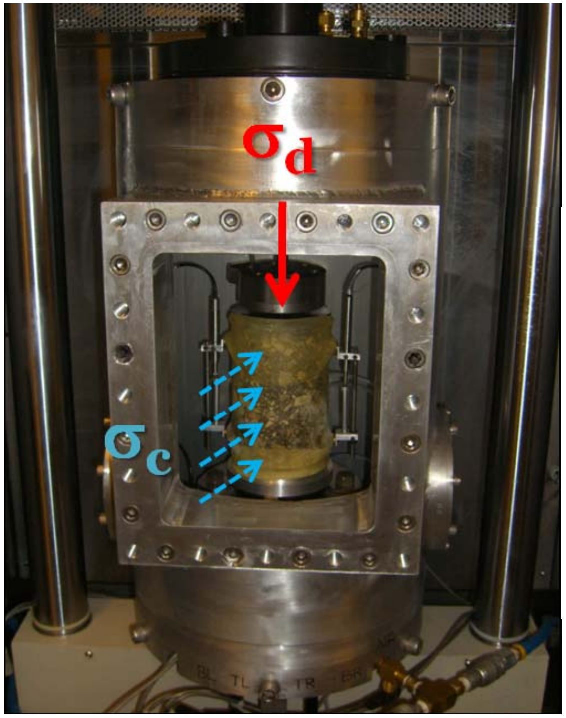
Asphalt Layer Behavior

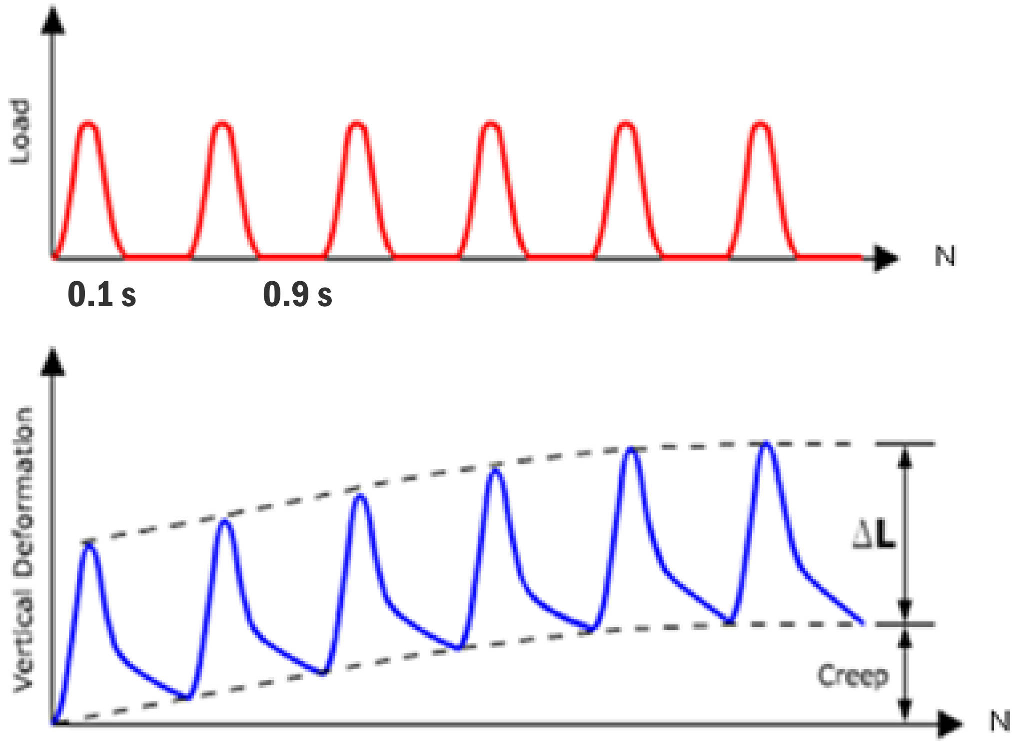
- Stress State
- Loading Rate
- Temperature

↓

Lab test that simulates field conditions

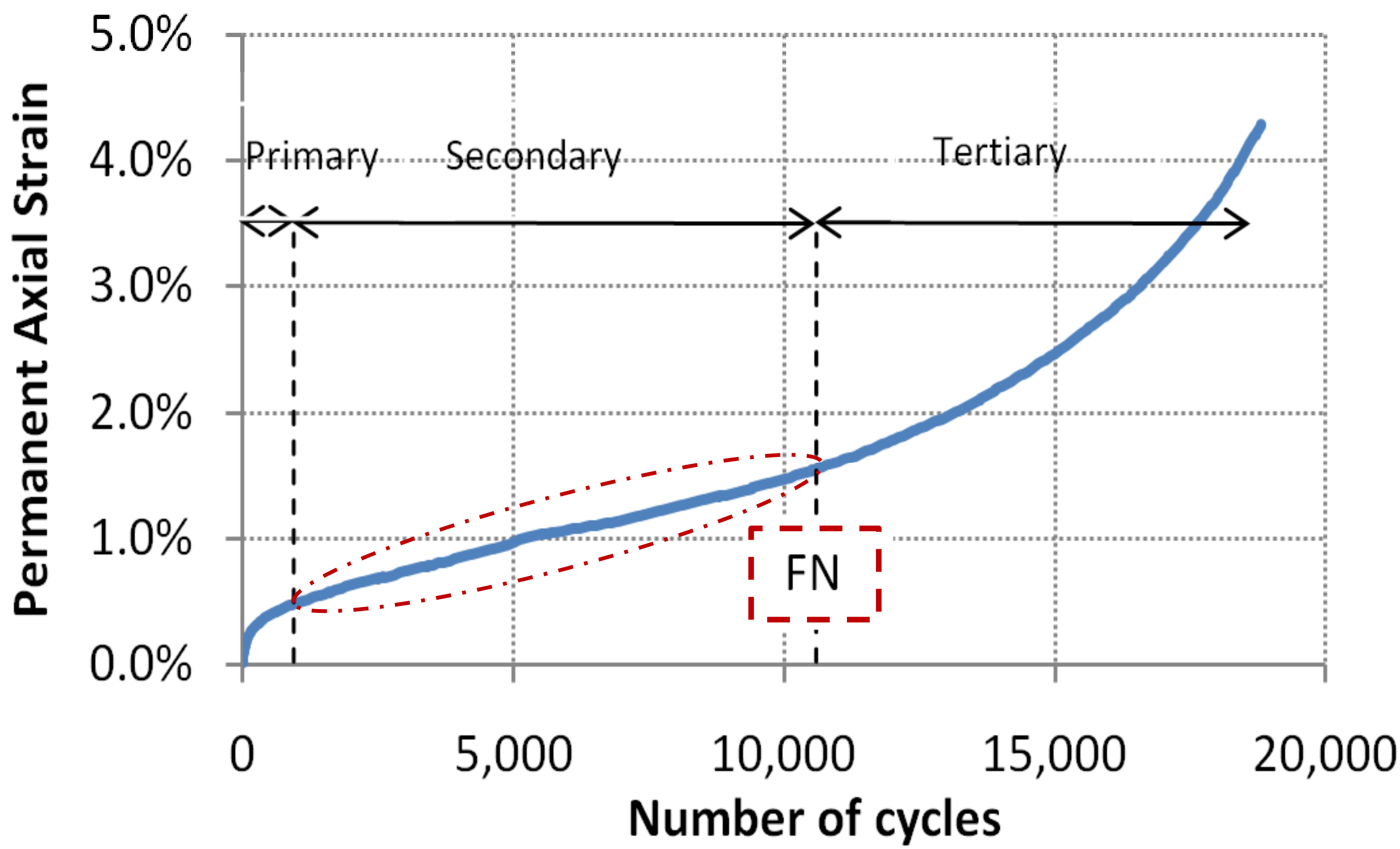
Flow number (FN) test



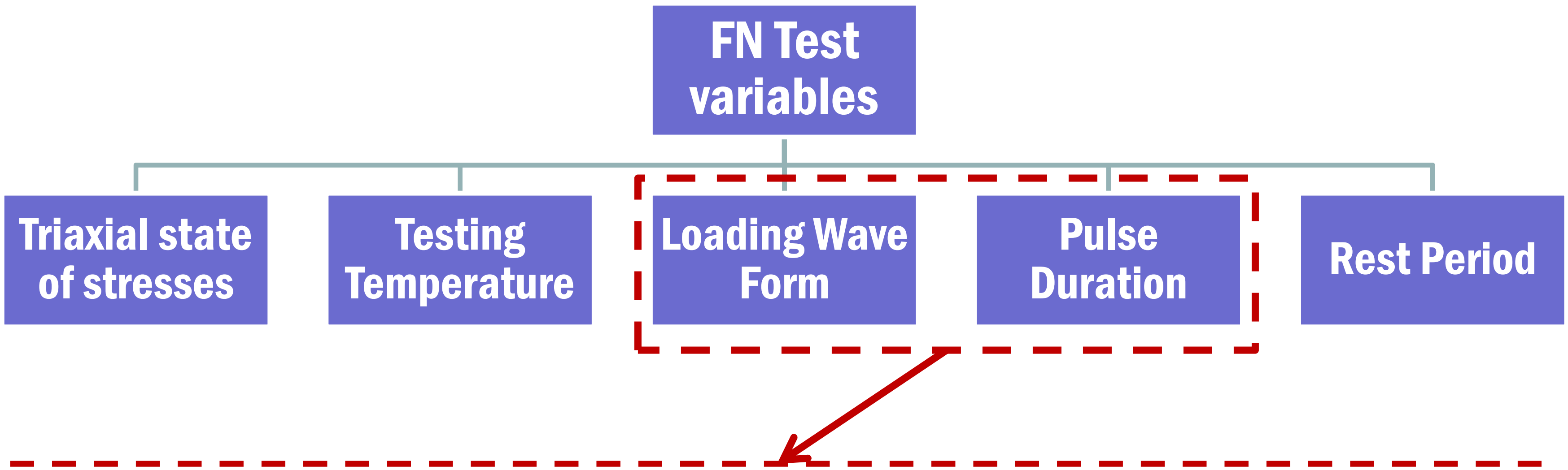


Flow number (FN) test

Permanent deformation Characterization



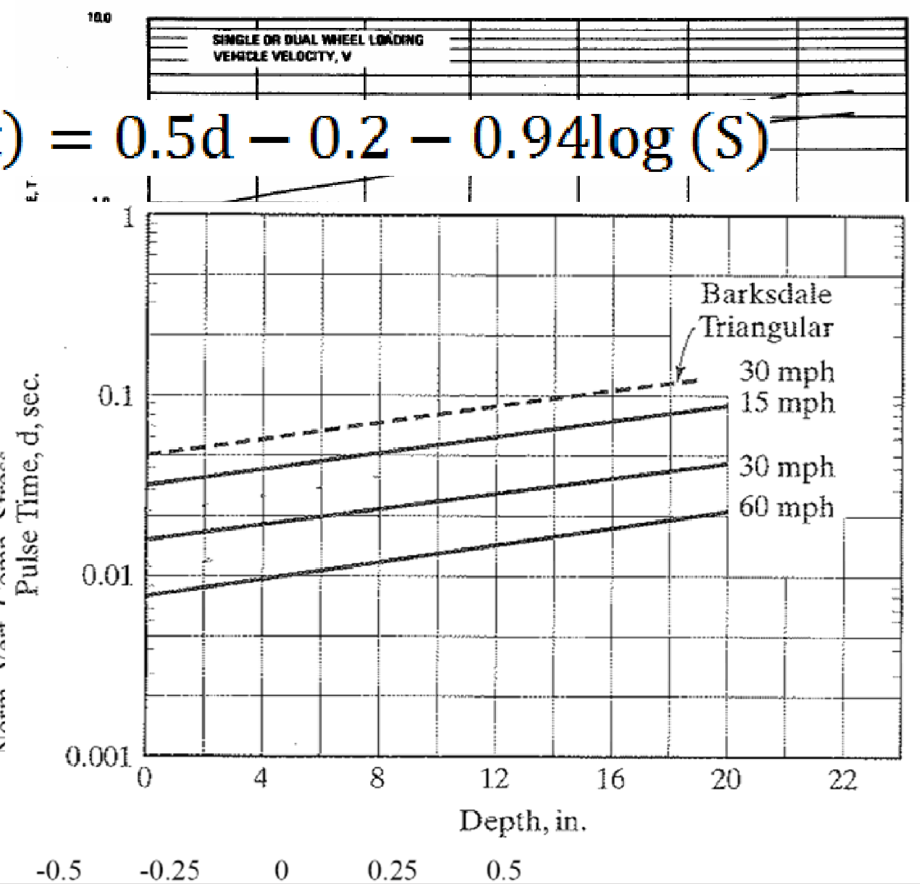
Objective



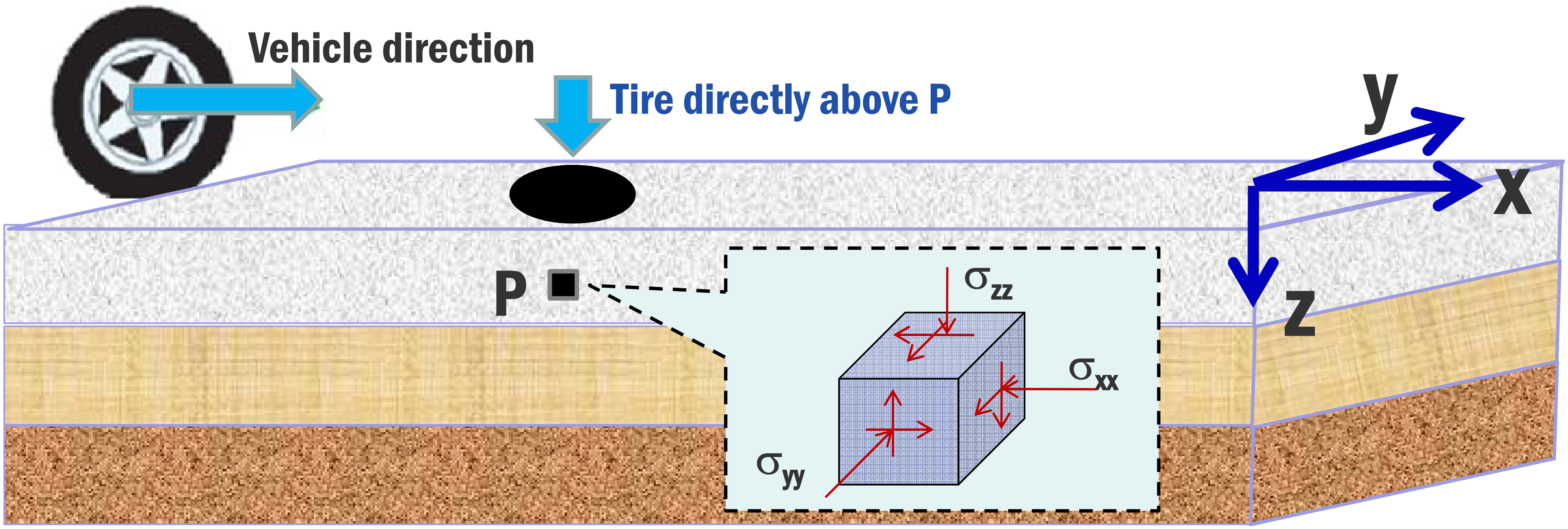
Provide recommendations for the characteristics of the *deviator loading pulse* in the flow number test

Pulse duration prediction

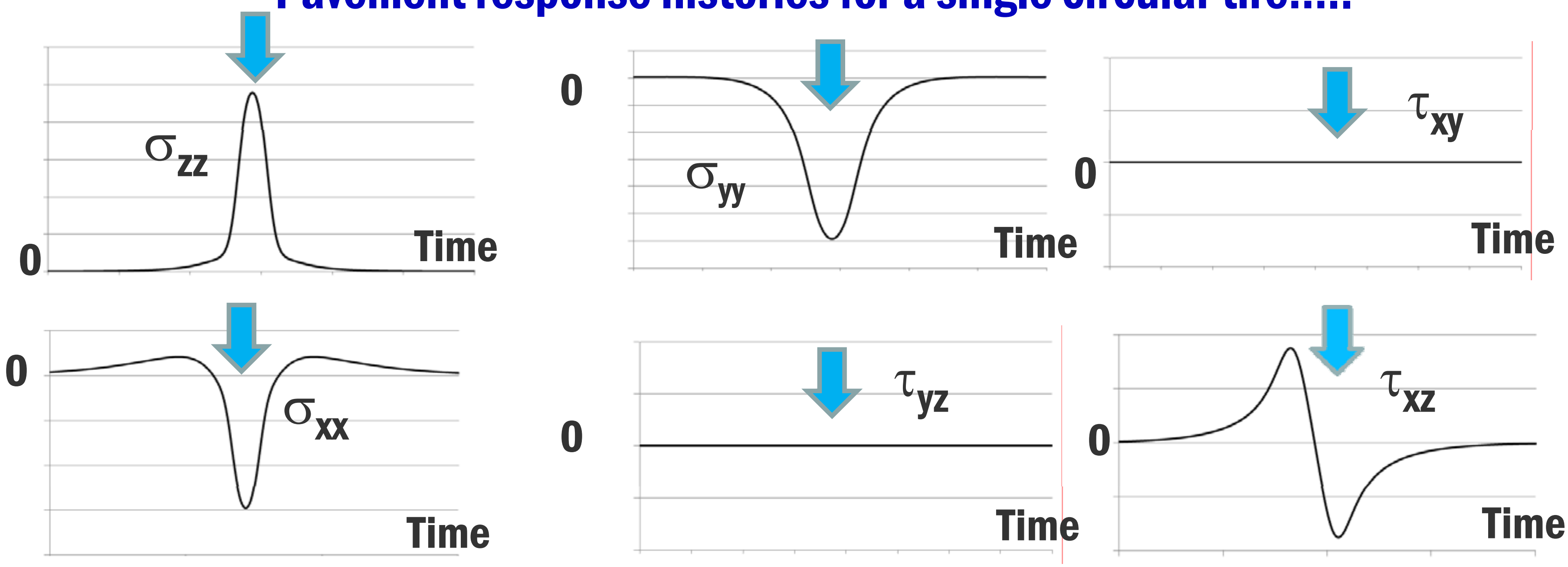
- Barksdale, 1971
- Brown, 1973 ➡ $\log(t) = 0.5d - 0.2 - 0.94\log(S)$
- McLean, 1974
- MEPDG, 2002
- Al-Qadi, 2008
- …



$\frac{f}{S}$



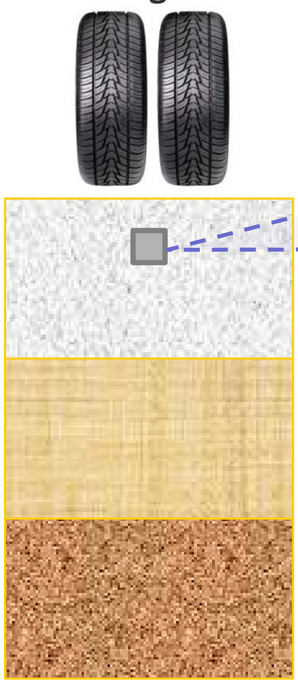
Pavement response histories for a single circular tire.....



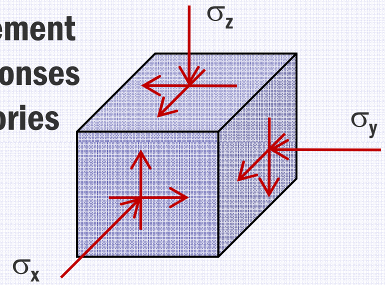
Question: What stress pulse shape to use in triaxial test?

Stress State in the Triaxial FN Test

Moving loads



Pavement responses histories



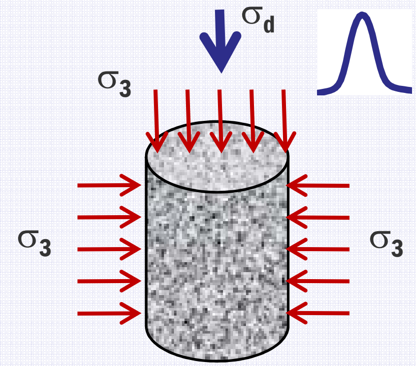
$$\sigma_{oct} = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) = \frac{1}{3}\bar{I}_1$$

$$|\tau_{oct}| = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} = \sqrt{\frac{2}{3}\bar{I}_{2D}}$$

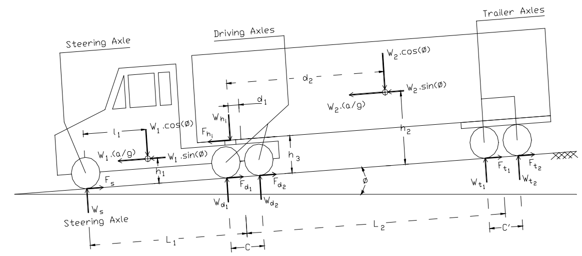
RLT / FN

$$\sigma_d = \frac{3}{\sqrt{2}}|\tau_{oct}|$$

$$\sigma_3 = \sigma_2 = \sigma_{oct} - \frac{\sigma_d}{3}$$

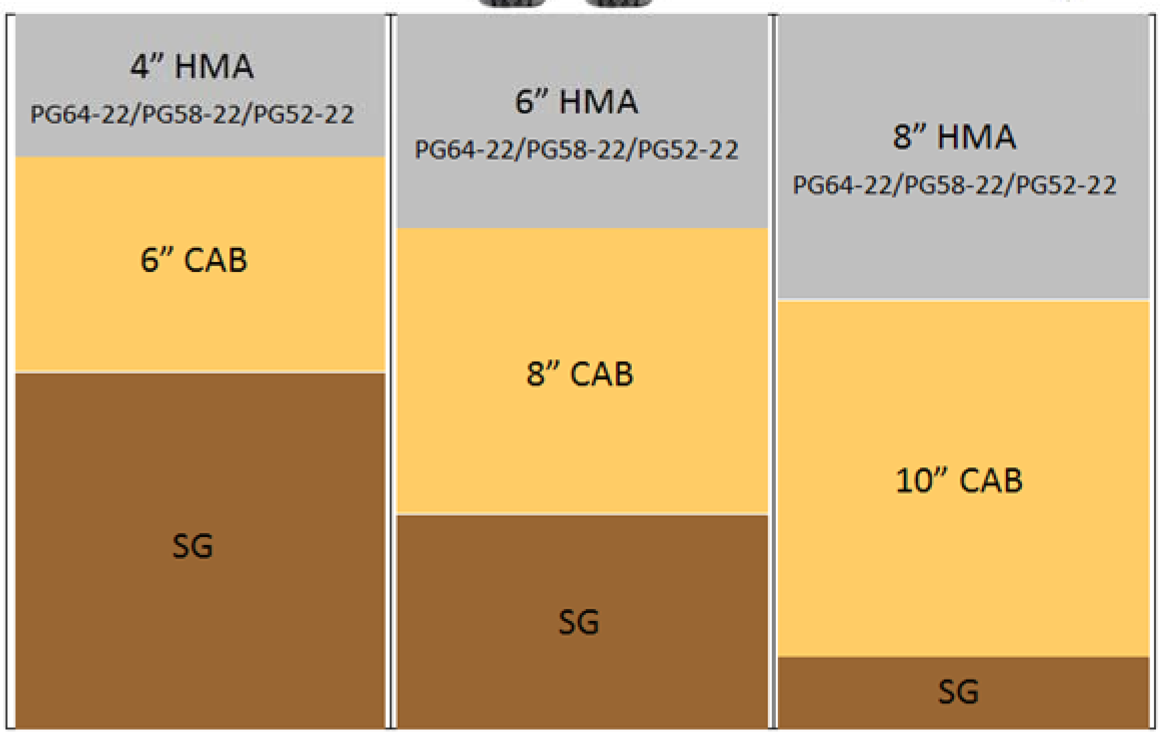


Database of pavement stresses time-histories

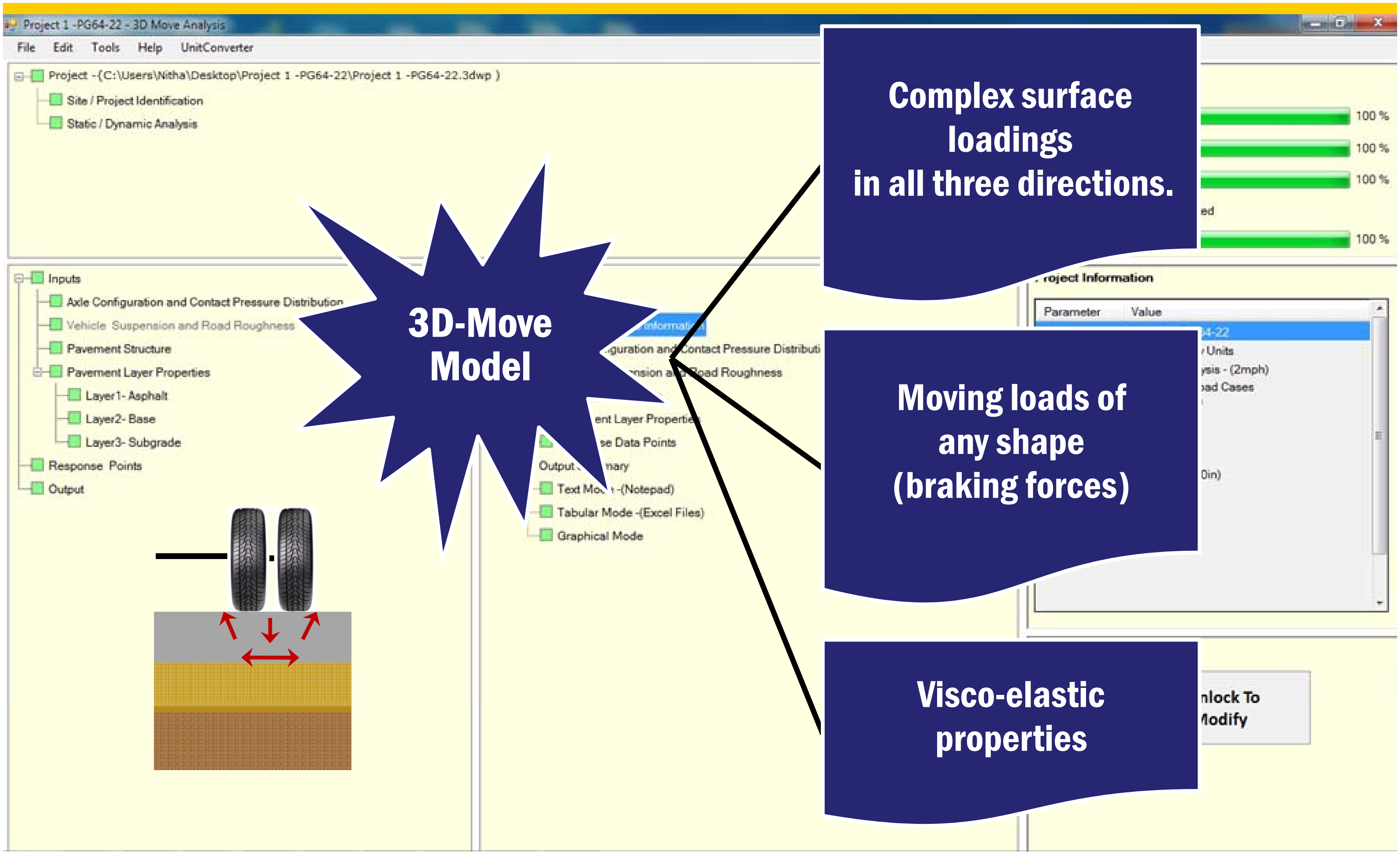


- 60 mph without braking
- 40 mph without braking
- 20 mph without braking
- 2 mph with braking
- 10 mph with braking
- 20 mph with braking

HMA layer temp: 104°F, 122°F, 140°F, and 158°F

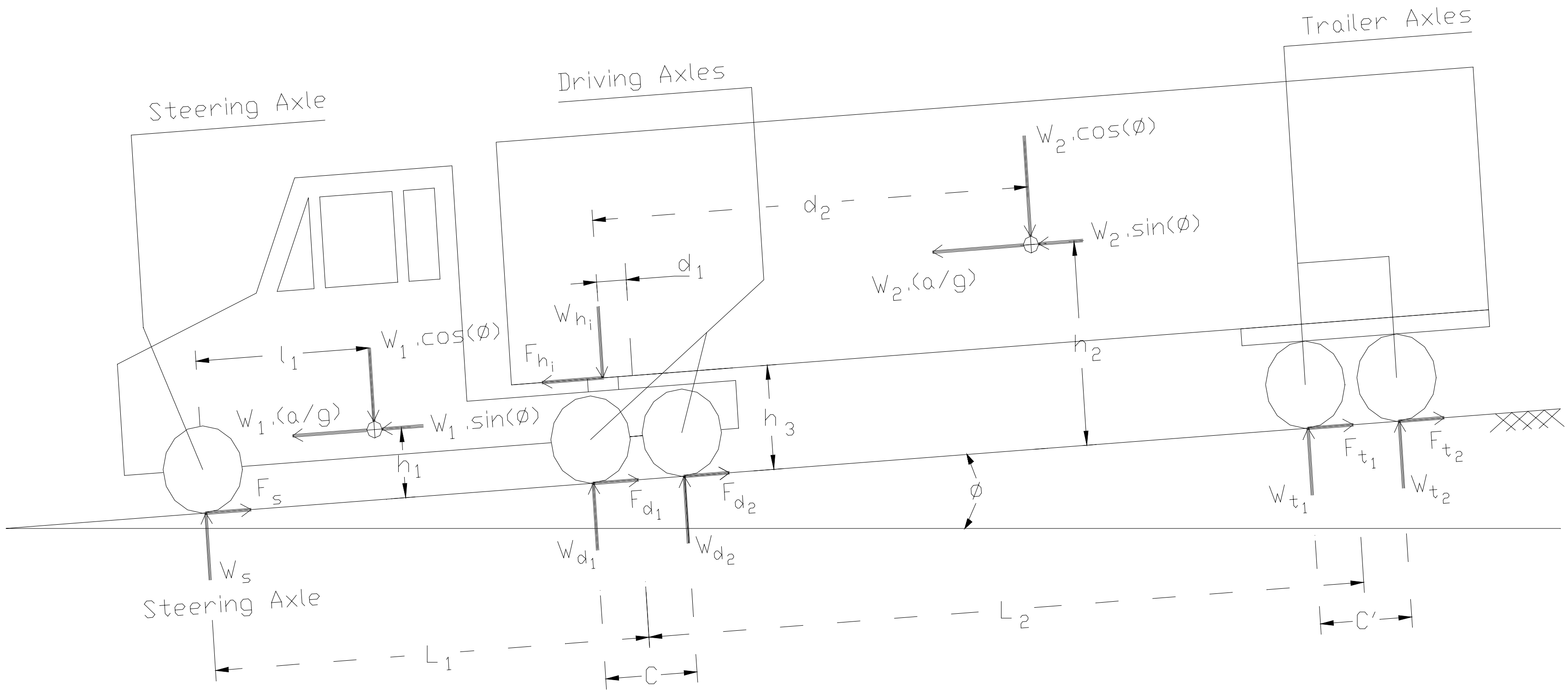


3D-Move Model



Semi-trailor Truck

dynamic load transfer → vertical loads on tires additive (+ or -) to static load



Braking = f(deceleration "a", braking forces)

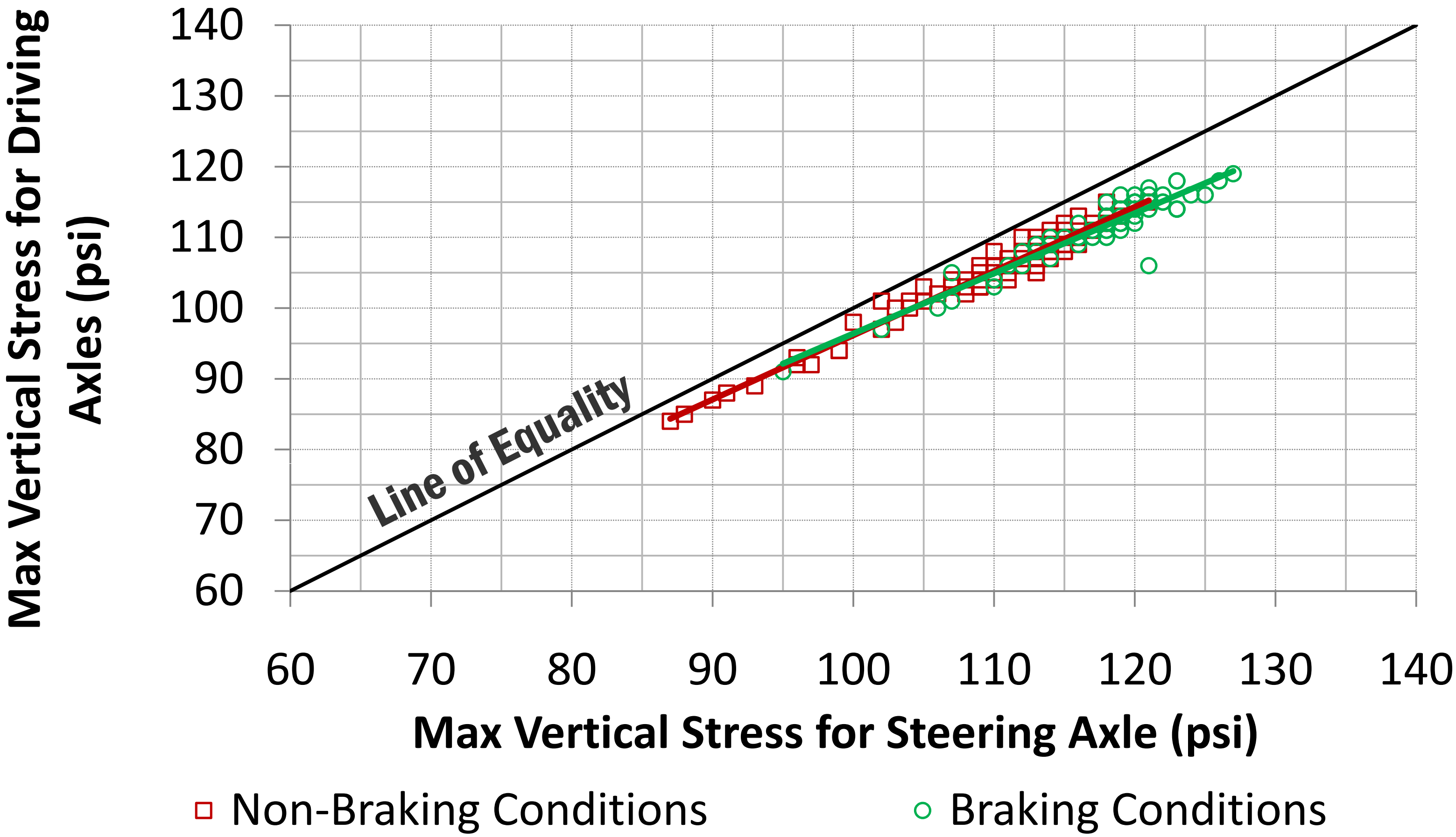
Semi-trailor Truck

- Load Distribution During Braking: 14 Unknowns
  - 11 equilibrium equations
  - 3 characteristic equations:
    - Application (treadle output) vs. actuation (brake chamber) pressure/axle
    - Brake force vs. actuation pressure on each axle.
    - Dynamic load transfer coefficient.

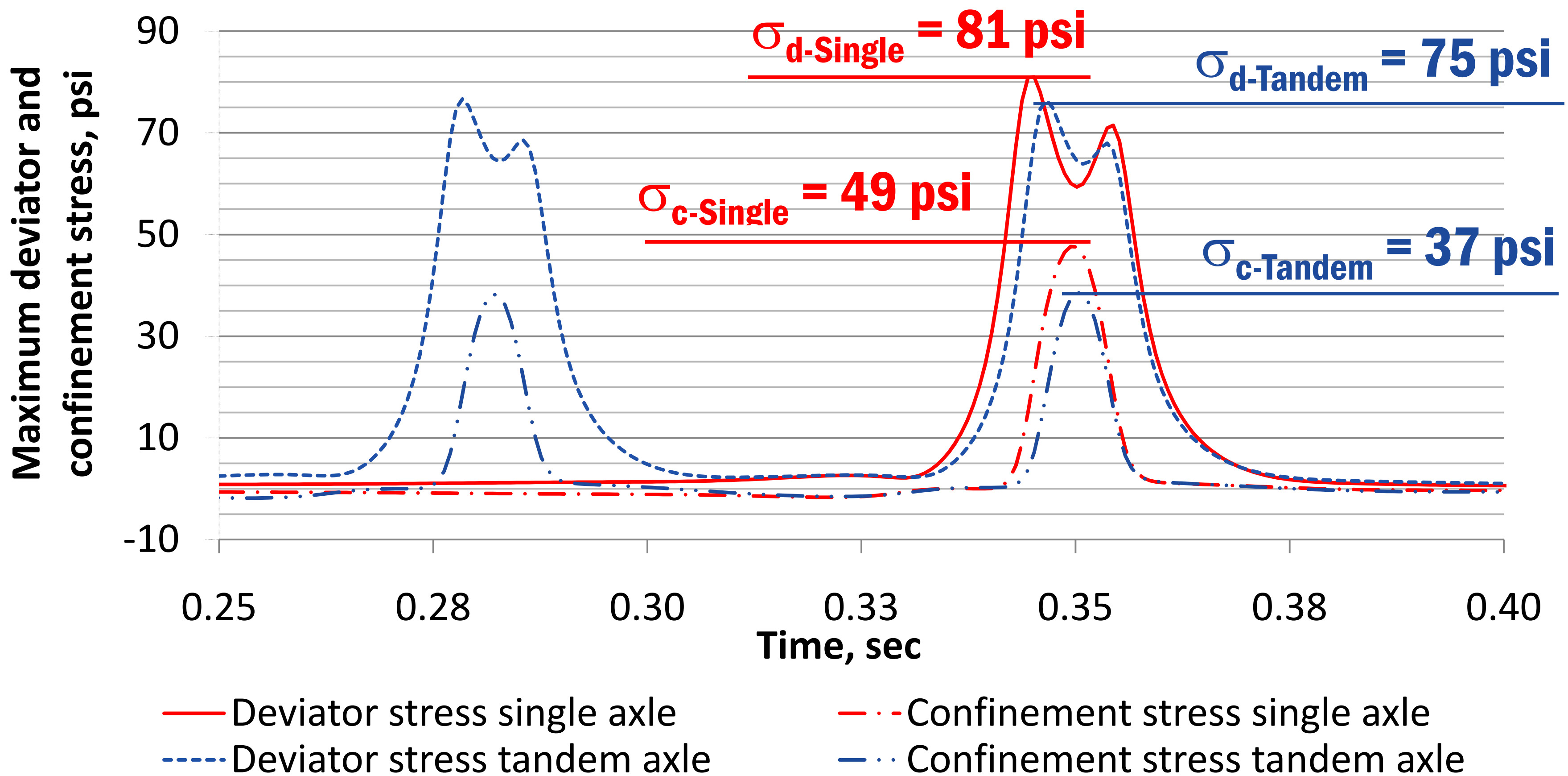
Equivalent deviator and confining stresses time-histories

- σ_d & σ_c were analyzed under Single and Tandem axles for every:
  - pavement structure
  - mixture type
  - pavement temperature
  - braking and non-braking conditions.

Equivalent deviator and confining stresses time-histories
Single vs. Tandem Axles



Equivalent deviator and confining stresses time-histories
Single vs. Tandem Axles (Non-braking)



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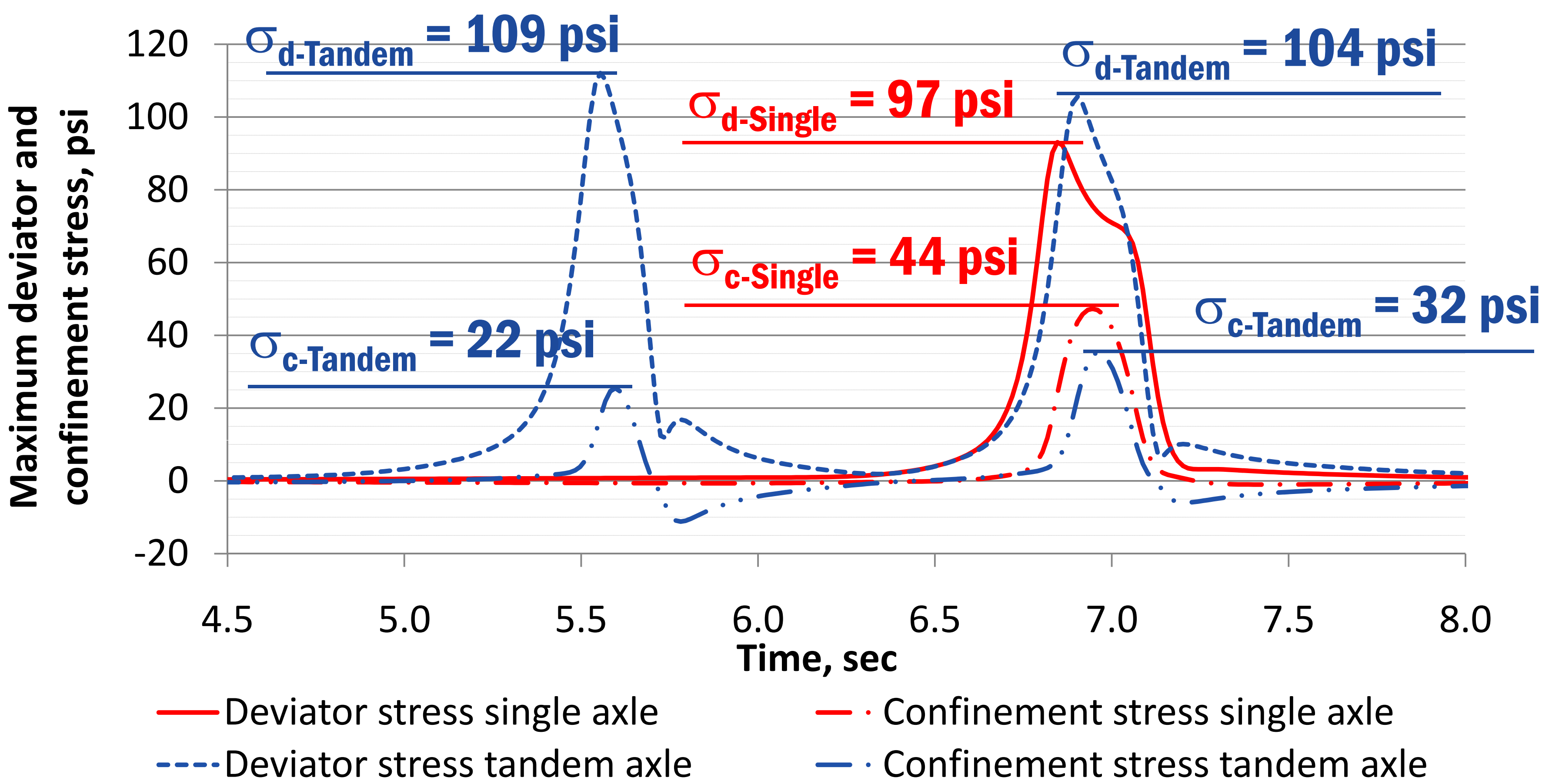
Equivalent deviator and confining stresses time-histories
Single vs. Tandem Axles (Braking)

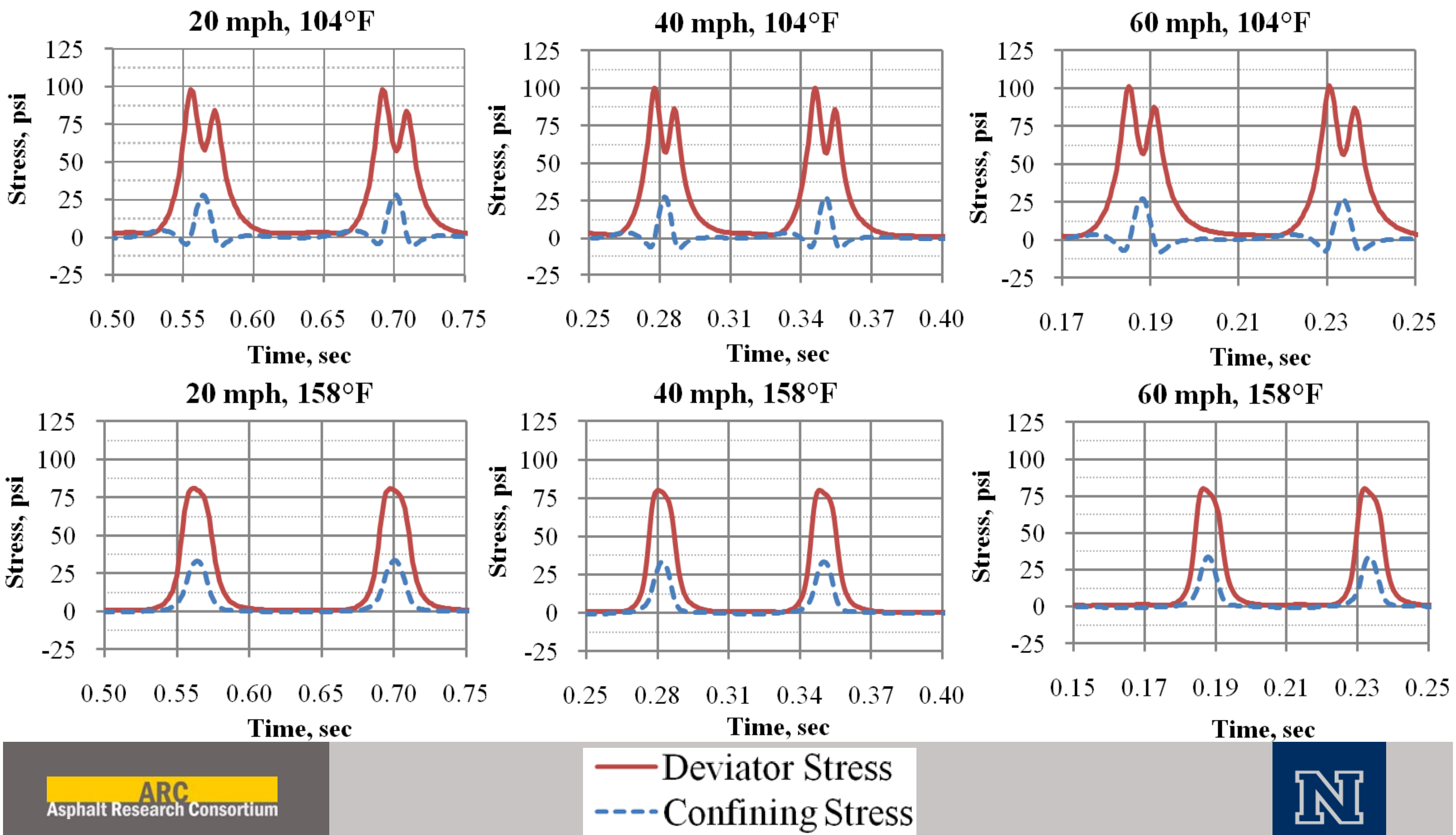


Equivalent deviator and confining stresses time-histories

- Tandem axle generates a more critical stress condition than the steering axle when the 3D state of stresses is analyzed.

- Stresses evaluated under tandem axles at 2-inch below pavement surface.

Equivalent deviator and confining stresses time-histories



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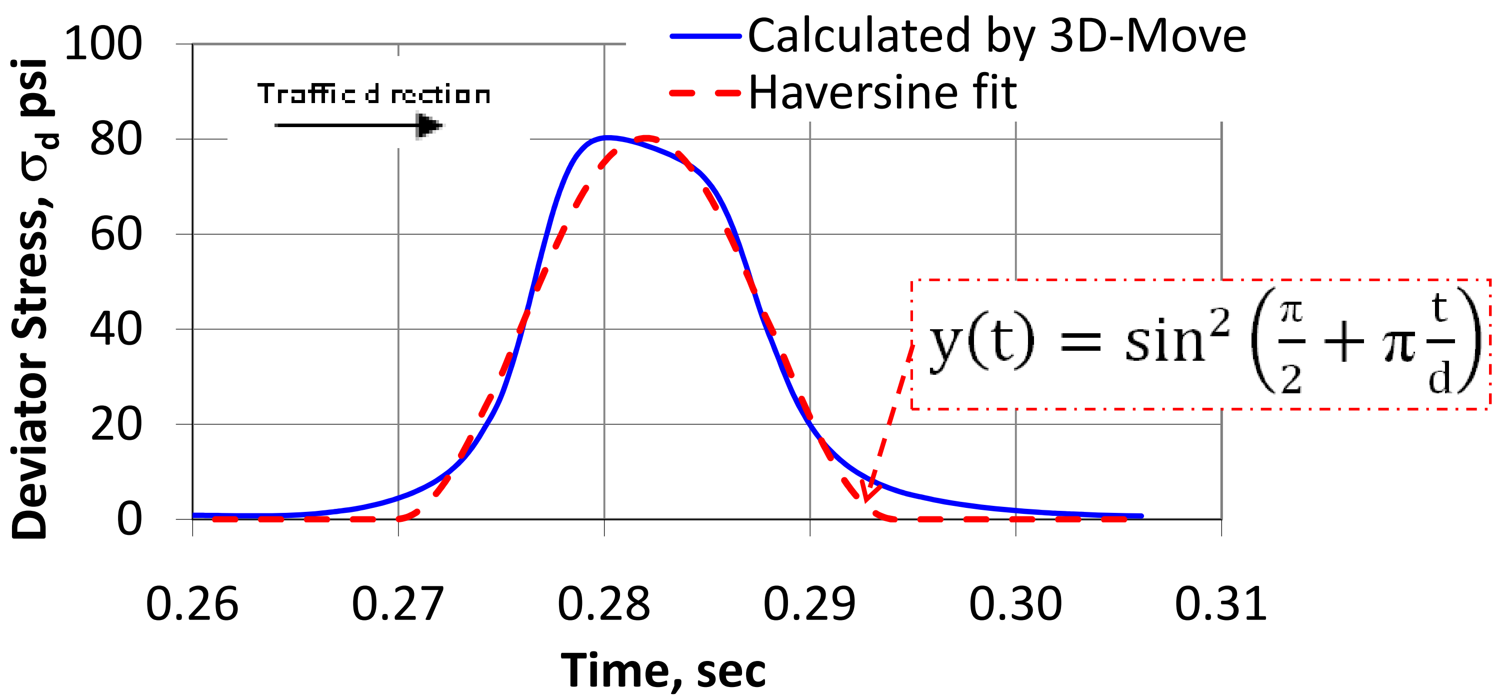
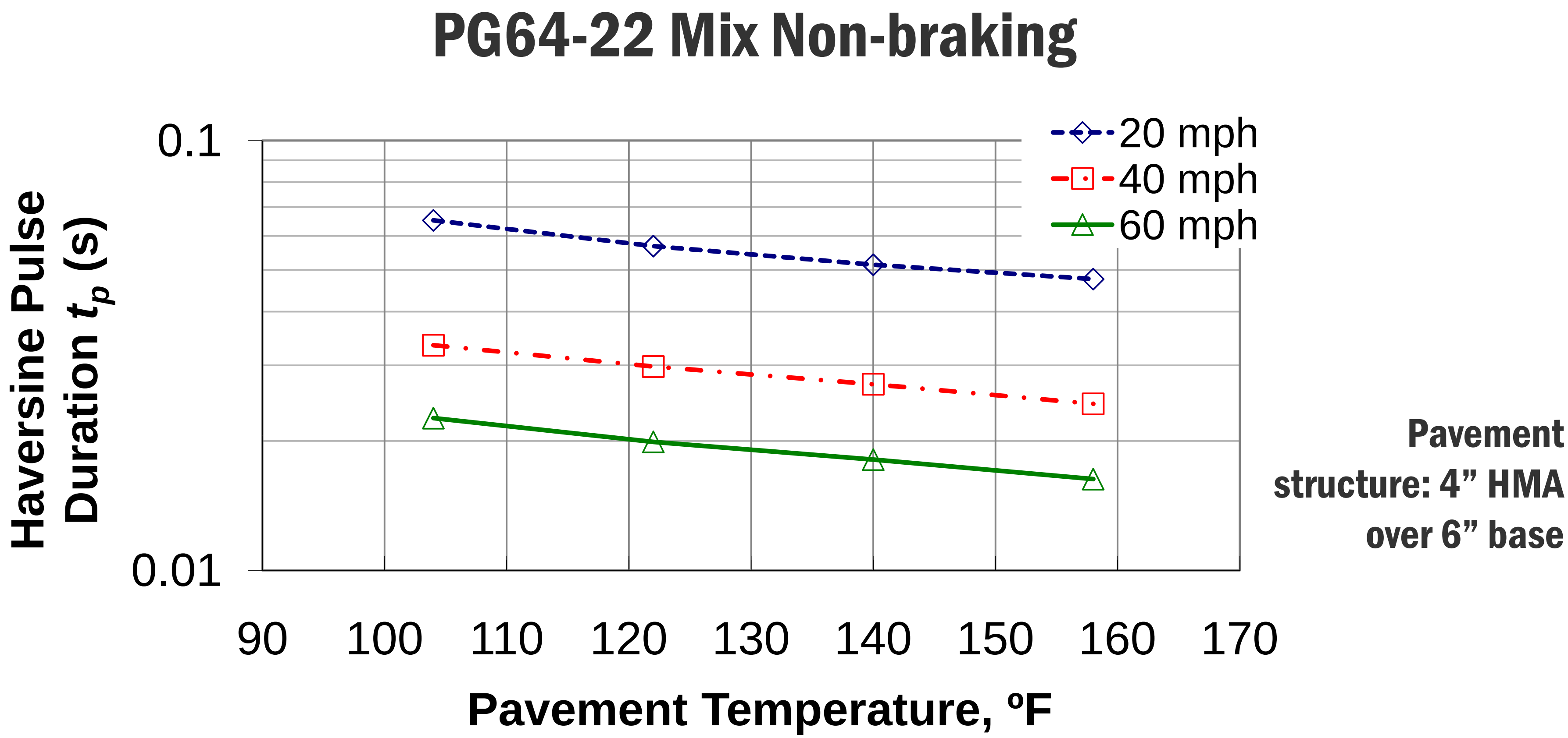
Equivalent deviator stress pulse duration

- Loading pulse characterized using σ_d at 2 inches.
- Best-fitting haversine wave shape.



Equivalent deviator stress pulse duration

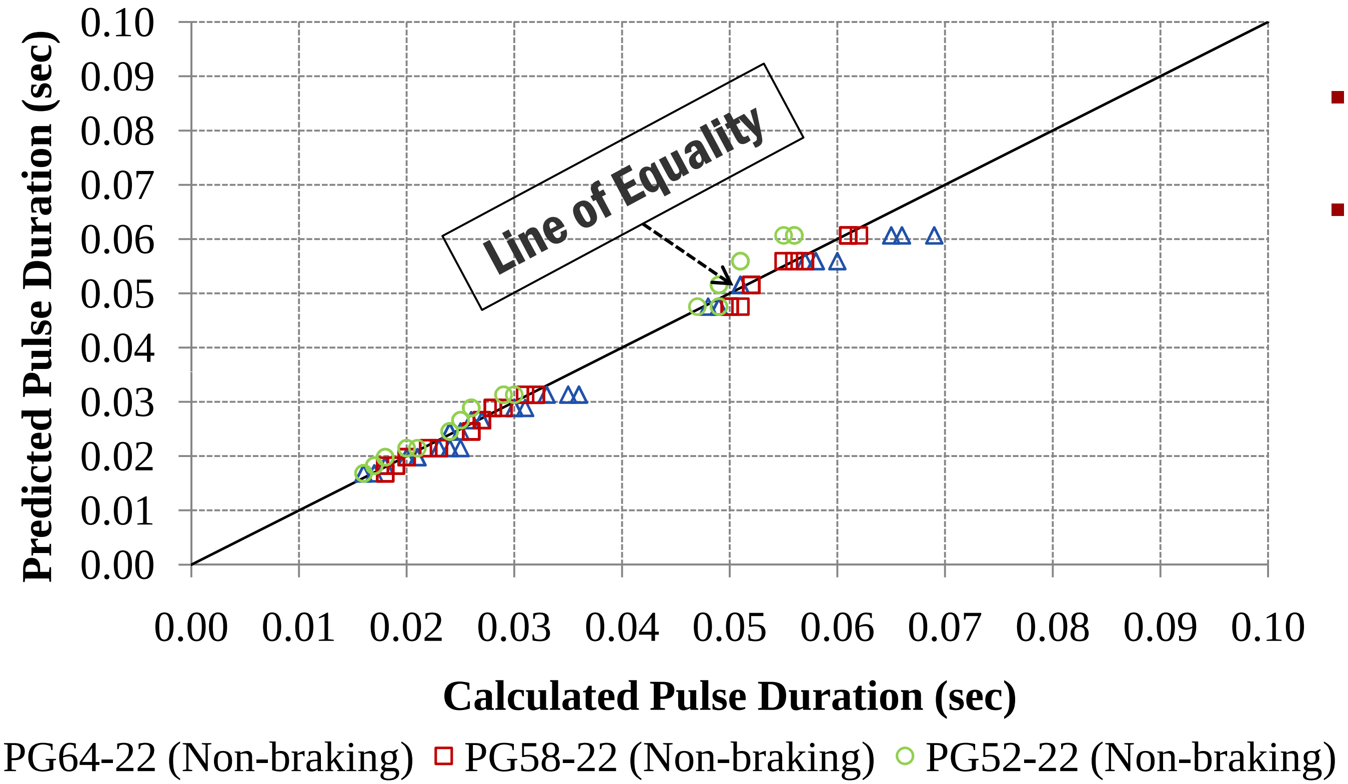
under tandem axle, 2 inches below pavement surface



Equivalent t_p at 2" below pavement surface

Non-braking Conditions (20-60 mph, 104-158°F)

$$\log(t_p) = -0.00353(T) - 0.0236(S) + 0.00015(S)^2 - 0.6654$$

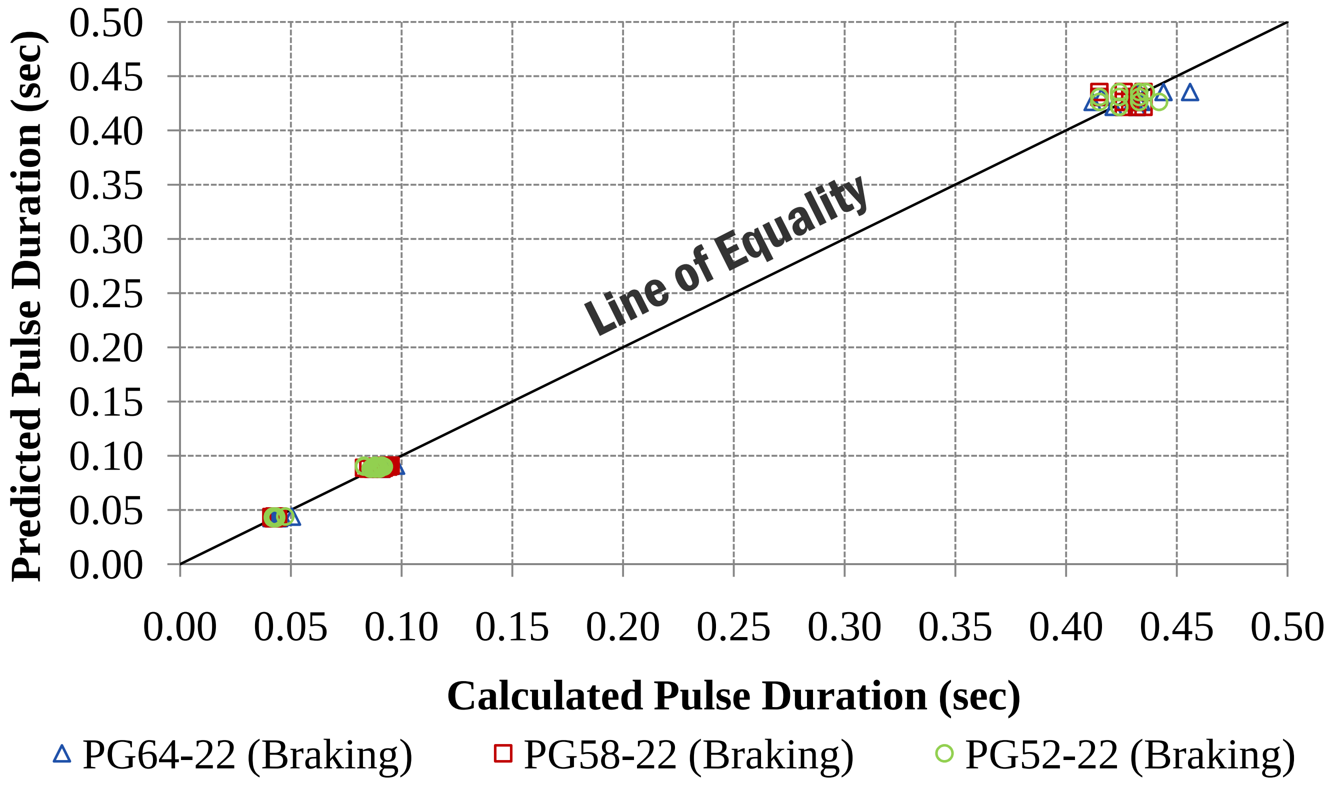


- T = asphalt layer temperature, ºC
- S = vehicle travelling speed, mph.

Equivalent t_p at 2” below pavement surface

Braking Conditions (2-20 mph, 104-158°F)

$$\log(t_p) = -0.000387(T) - 0.05531(S) - 0.23603$$



- T = asphalt layer temperature, ºC
- S = vehicle travelling speed, mph.

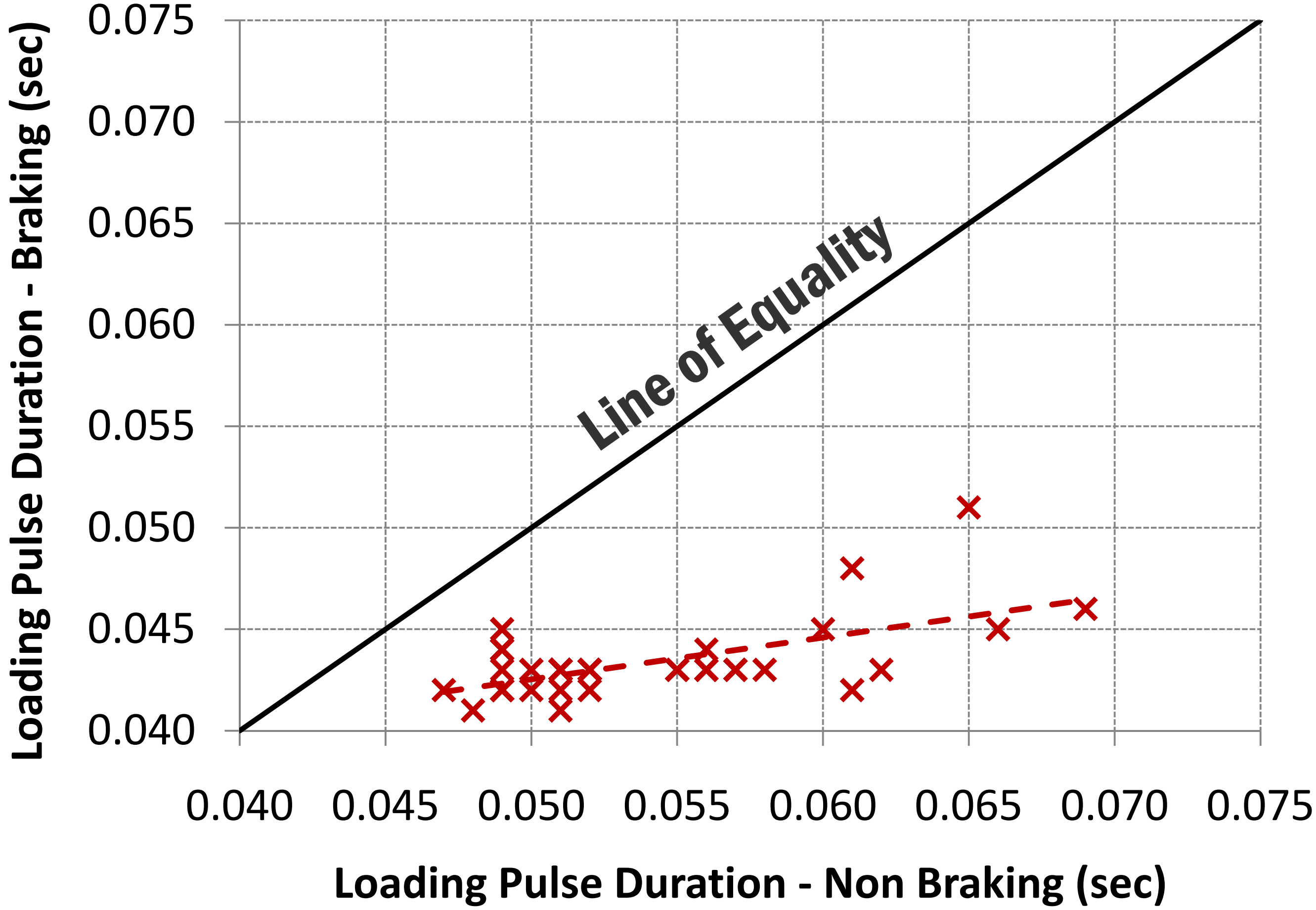
Equivalent Deviator Stress Pulse Duration (t_p) at 2” below pavement surface

	Non-Braking	Braking
Speed	20-60 mph	2-20 mph
Equivalent Deviator stress pulse (t_p)	0.016-0.069 sec	0.041-0.456 sec

< 0.1 sec typically applied to FN test
(*except for braking at 2 mph*)

Equivalent deviator stress pulse duration

Braking vs. Non-braking at 20 mph

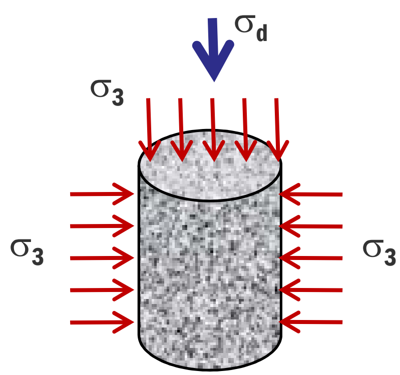


12% to 29% reduction in pulse time

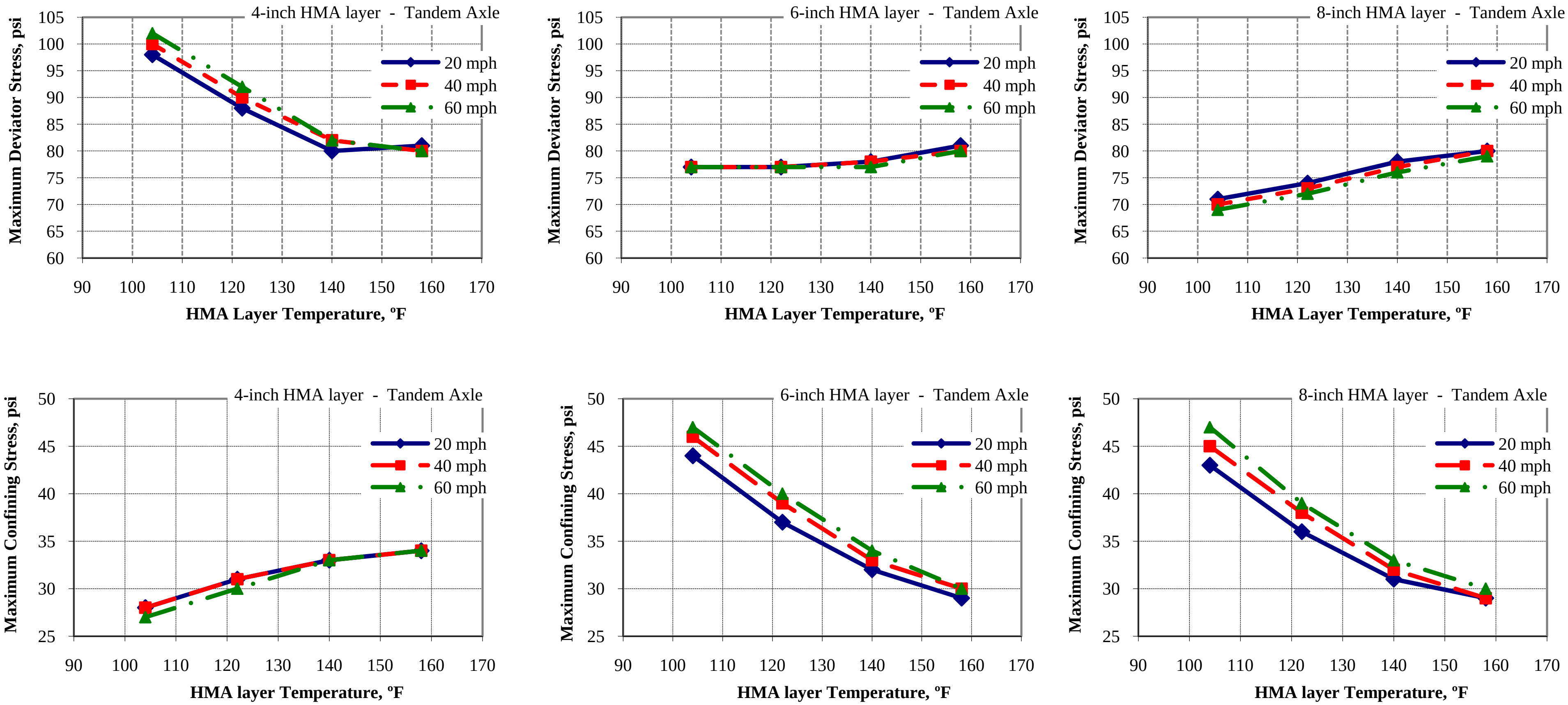
Equivalent Deviator Stress Pulse Duration (t_p) at 2” below pavement surface

Non-braking condition seems to result in a more critical condition than braking condition.

Evaluate the magnitudes of σ_d and σ_c under braking and non-braking conditions

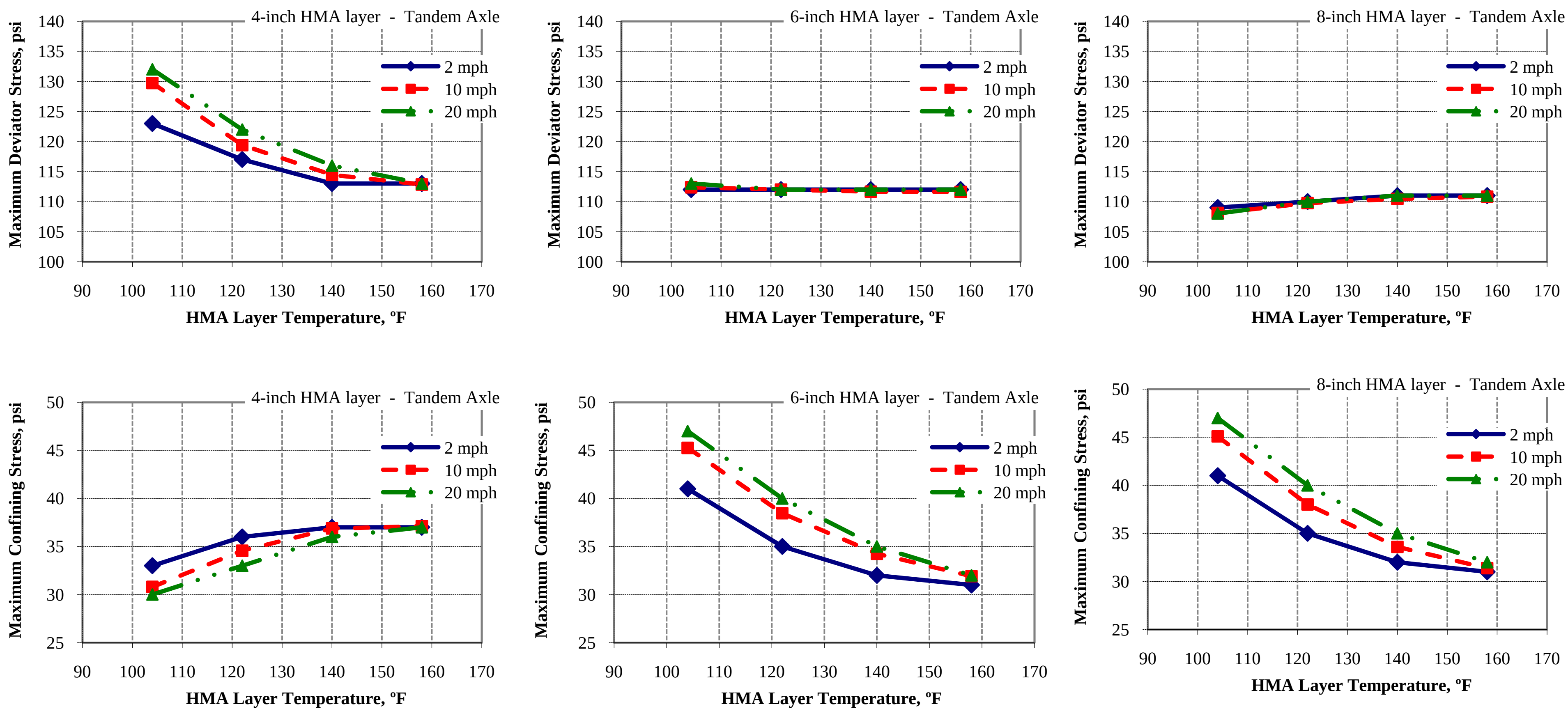


Maximum equivalent σ_d and σ_c stresses



PG64-22 Mix for non-braking conditions

Maximum equivalent σ_d and σ_c stresses



PG64-22 Mix for braking conditions

Maximum equivalent σ_d and σ_c stresses

- **Predictive Equations for:**
  - **Equivalent max deviator stress, σ_d**
  - **Equivalent max confining stress, $\sigma_c = \sigma_3$**

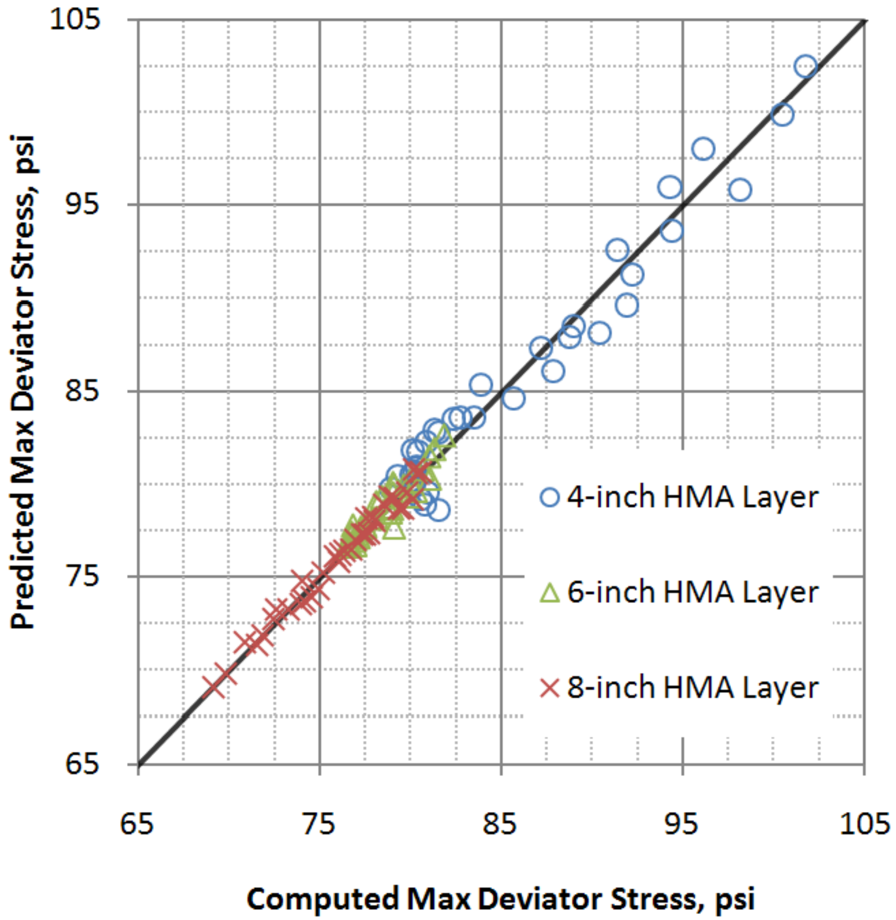
at 2 inches below pavement surface

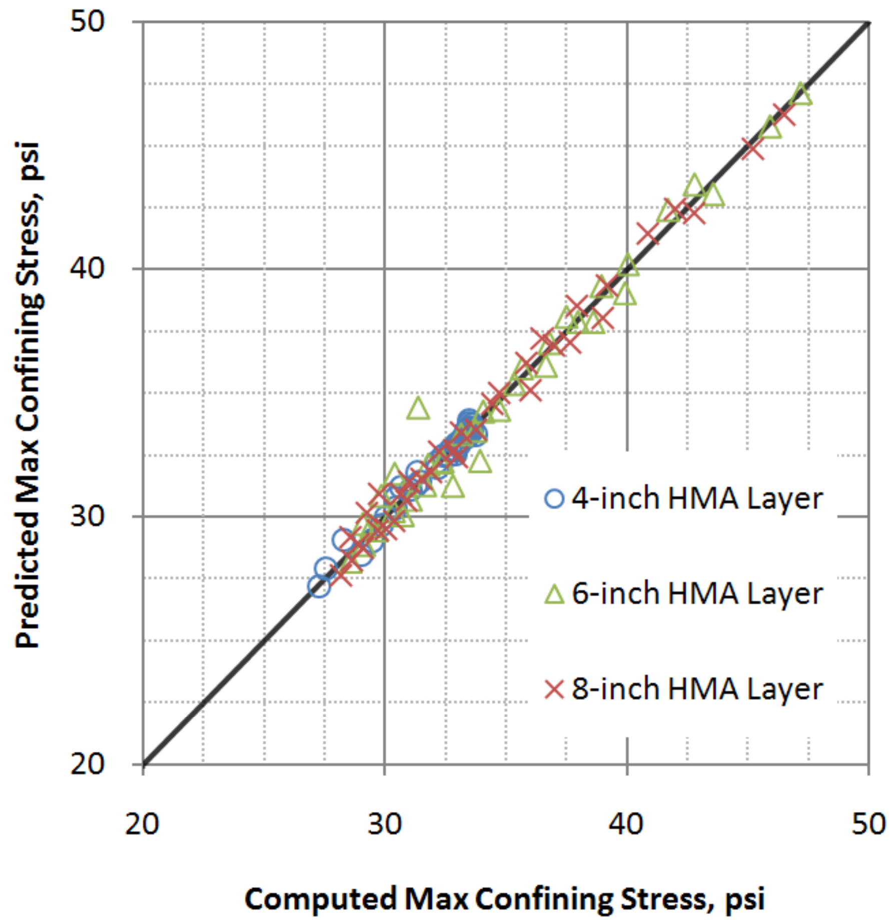
Braking and Non-Braking Conditions

Function of *AC layer thickness*, *T*, *E, *S*, *interaction terms***

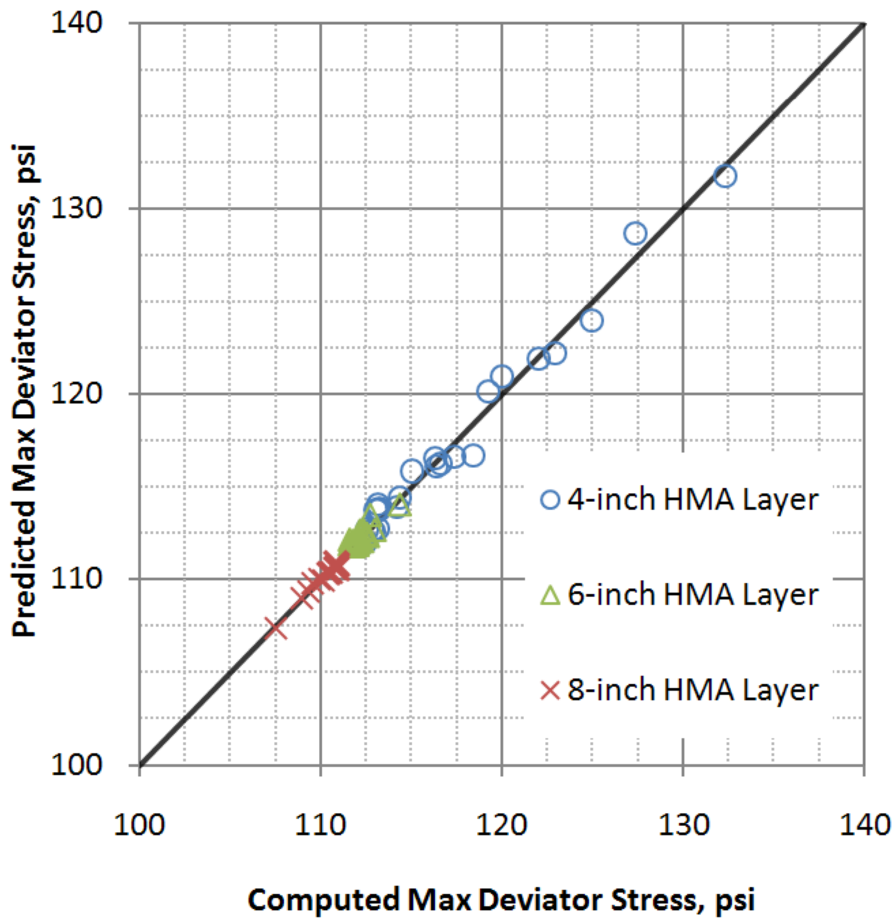
Equivalent Deviator & Confining Stresses at 2”

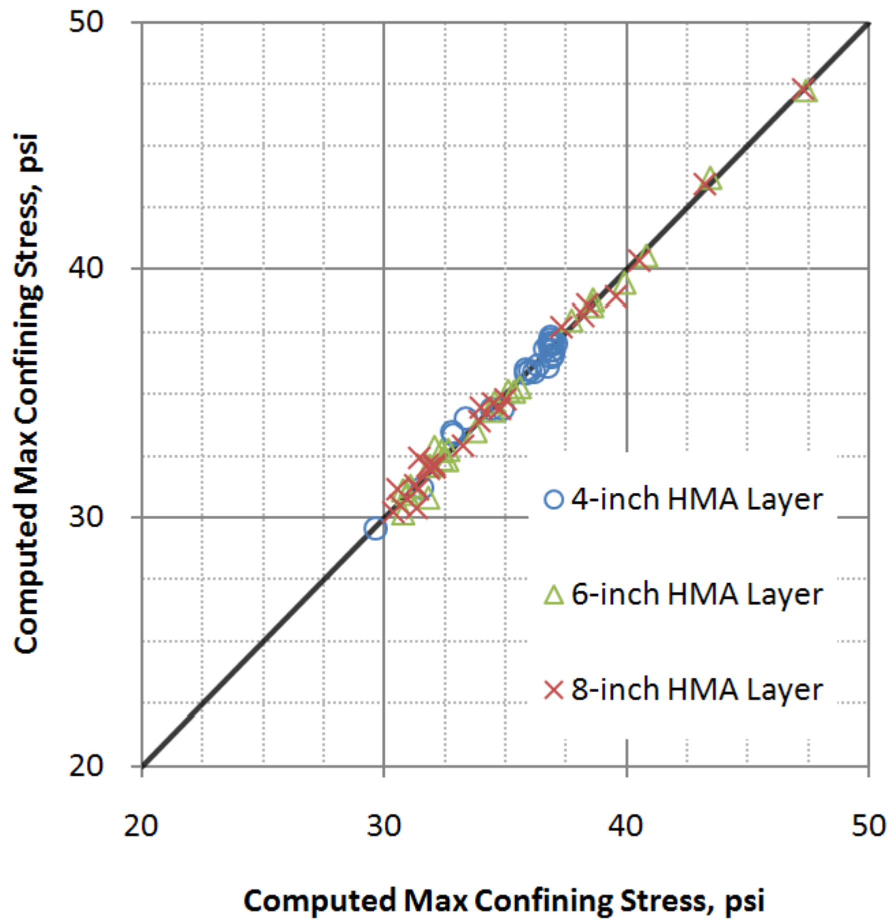
Non-Braking Conditions





Equivalent Deviator & Confining Stresses at 2”
Braking Conditions





Equivalent Deviator & Confining Stresses at 2" Below Pavement Surface

Non-braking conditions:

– σ_d ranged from 69 to 102 psi

– σ_c ranged from 27 to 47 psi

slight increase (5%) in σ_c

40% increase in σ_d

Braking conditions:

– σ_d ranged from 108 to 132 psi

– σ_c ranged from 30 to 47 psi

Summary and conclusions

- Equivalent deviator stress pulse duration (t_p) at 2” below the pavement is function of
  - vehicle speed, and
  - pavement temperature.
- Neither pavement thickness nor mixture properties significantly impacted t_p at 2” below pavement surface.

Summary and conclusions

- Standard pulse time loading of 0.1 sec does not simulate actual traffic-induced deviator stress pulse duration.
- Braking conditions, though it generates interface shear stresses, leads to lower deviator pulse duration & higher amplitude.

Summary and conclusions

- Amplitude of the equivalent triaxial deviator and confining stresses are highly affected by:
  - Mixture's stiffness
  - Pavement effective temperature
  - Vehicle speed.

Thank you for your attention!!!

- **Acknowledgments**

  – This work is part of the overall effort in the Asphalt Research Consortium (ARC) work element E2c: "Critically Designed HMA Mixtures." (www.arc.unr.edu)

  – Authors gratefully acknowledge the FHWA support.